

Enhancing CRTM all-sky simulations and implementation of a new active sensor module

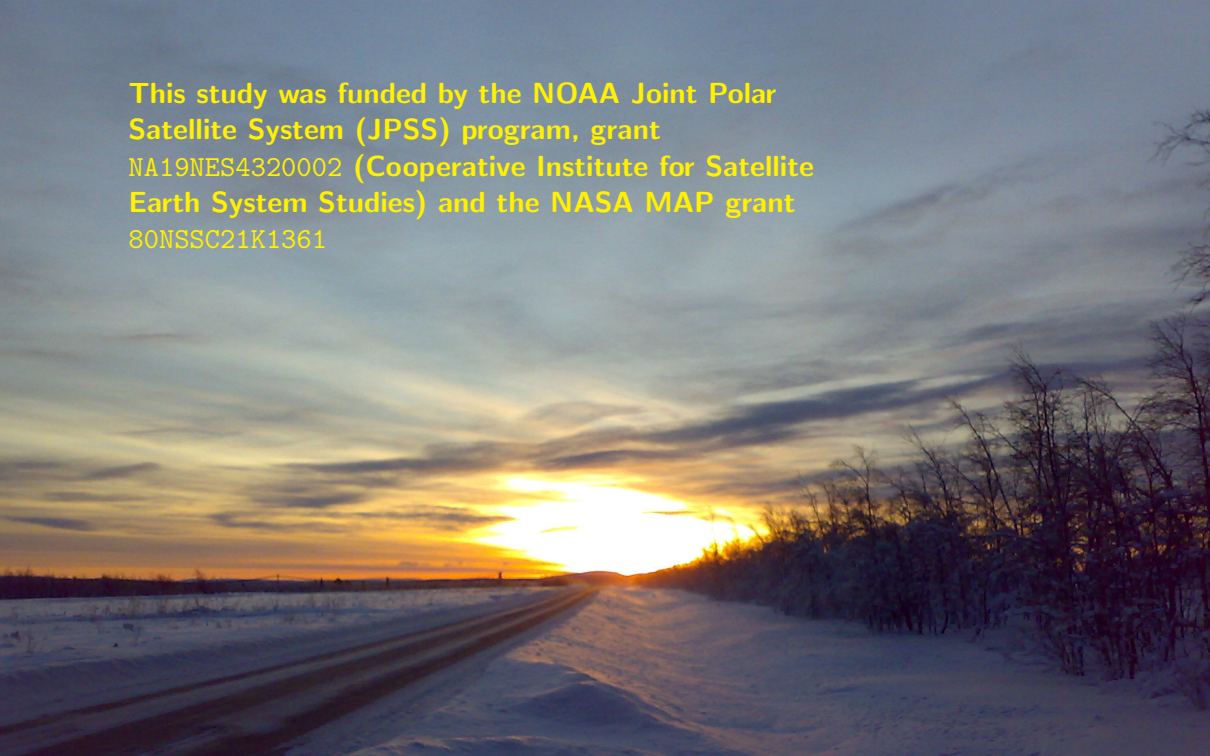
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With thanks to: Benjamin Johnsson, Patrick Stegmann, Alan Geer,
Patrick Eriksson, Ronald Gelaro, Satya Kalluri, Will McCarty

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Introduction & Importance

The Discrete Dipole Approximation

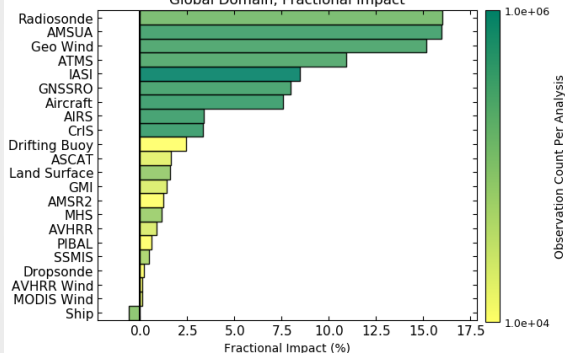
CRTM Simulations for Hurricane Irma

The CRTM Radar Simulator

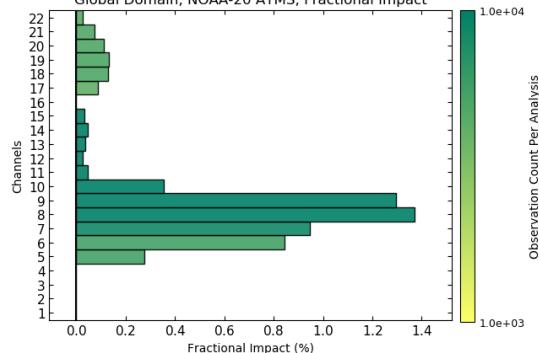
Evaluation of Radar Simulator

Impact of Observations on NWP Forecasts

GEOS 24h Observation Impact Summary
25 Jan 2022-24 Jan 2023 00z
Global Domain, Fractional Impact



GEOS 24h Observation Impact Per Channel
25 Jan 2022-24 Jan 2023 00z
Global Domain, NOAA-20 ATMS, Fractional Impact



All-weather radiative transfer calculations

Cost function for 3D-Var Data Assimilation:

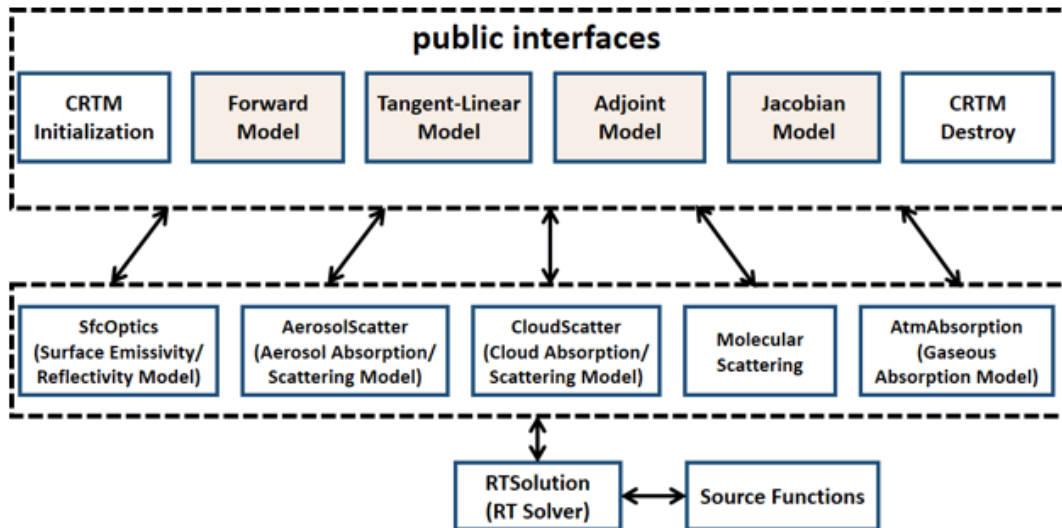
$$J(\mathbf{x}) = \overbrace{\frac{1}{2}(\mathbf{x} - \mathbf{x}_b)^T \mathbf{B}^{-1}(\mathbf{x} - \mathbf{x}_b)}^{J_b} + \overbrace{\frac{1}{2}(H(\mathbf{x}) - \mathbf{y})^T \mathbf{R}^{-1}(H(\mathbf{x}) - \mathbf{y})}^{J_o}$$

Relation between the observations (y) and the forward operator (H) can be expressed as: $y = H(\mathbf{x}, \mathbf{p}_b, \mathbf{p}_s) + \epsilon$

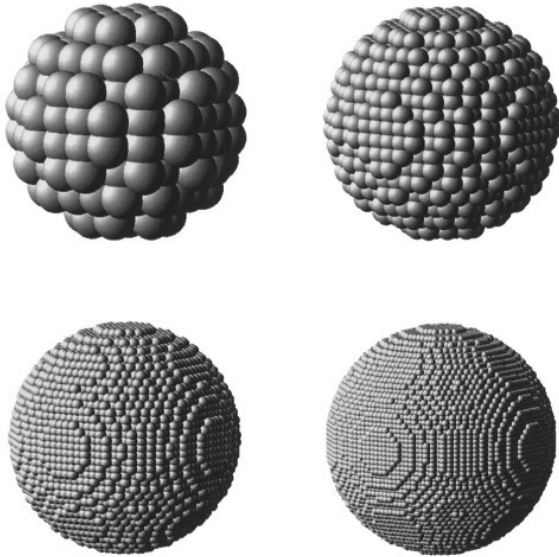
\mathbf{x} state vector, \mathbf{p}_b parameters such as size distribution of hydrometers, \mathbf{p}_s indicates the scattering parameters (e.g., phase function, scattering coefficient, asymmetry factor)

The scattering parameters highly depend on the shape of hydrometeors and current CRTM cloud lookup tables assume spherical shapes for all hydrometeors (frozen or liquid)!

Community Radiative Transfer Model



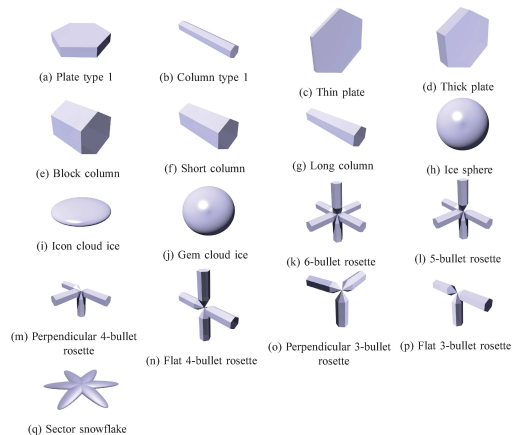
The Discrete Dipole Approximation



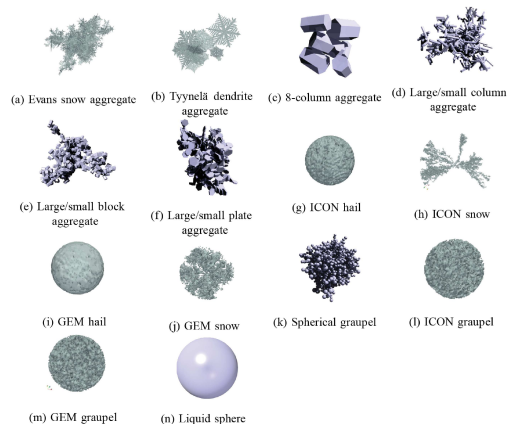
In the DDA technique, scattering and absorption are approximated by a finite array of small polarized dipoles. DDA was originally introduced by DeVoe in 1964. The dataset was developed by Eriksson et al (2018) using the Amsterdam DDA (ADDA, Yurkin et al., 2020) and includes single scattering properties of a large number of frozen and liquid habits.

Laczik et al., Appl. Opt. 35, 3736-3745 (1996)
Used with permission

ARTS DDA Database



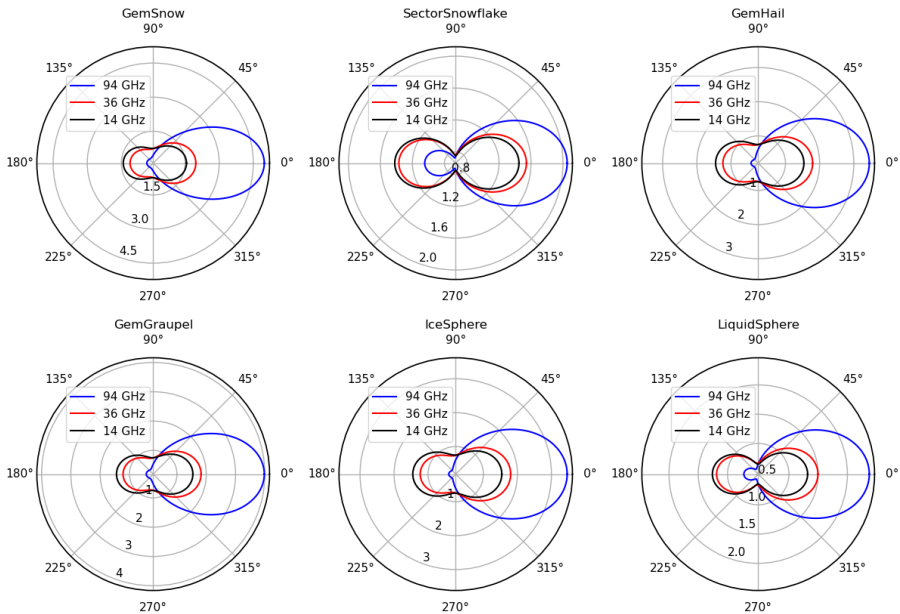
(a) Single crystal



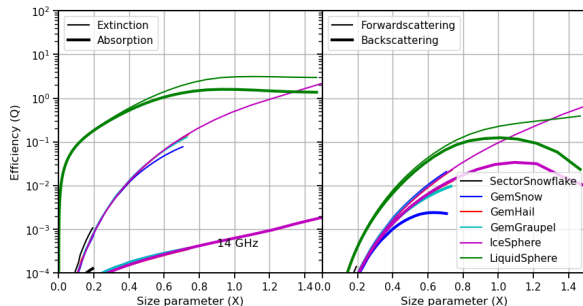
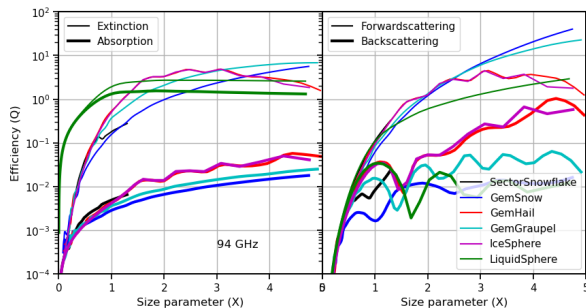
(b) Aggregates and liquid habits

Figure 4: Single crystal, aggregate, and liquid habits included in the database generated by *Eriksson et al.* (2018). Note that although habits "h" and "j" may look identical in the image, they have different aspect ratio.

The Phase Functions

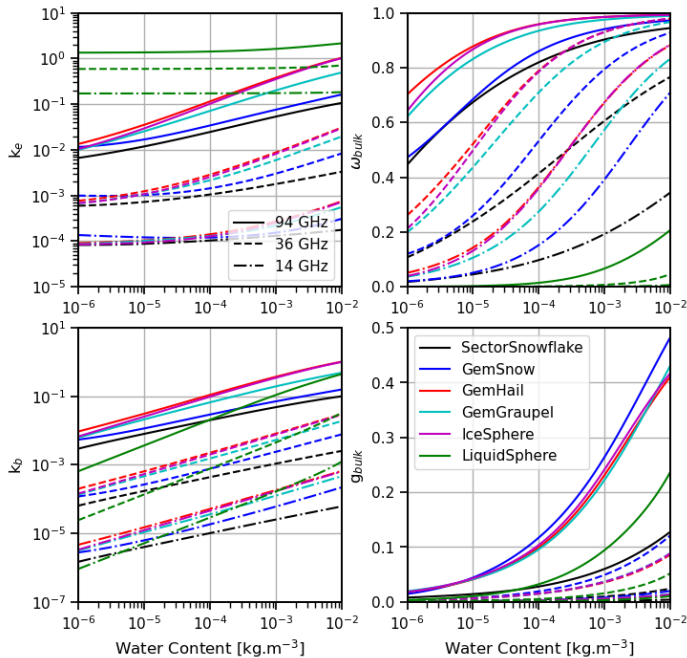


Single Scattering Efficiencies



$$Q_{\lambda} = \frac{\sigma_{\lambda}}{\pi r^2} \quad x = \frac{\pi D}{\lambda}$$

Extinction and backscattering efficiencies from the ARTS database for several different habits (Temp: 260 K)

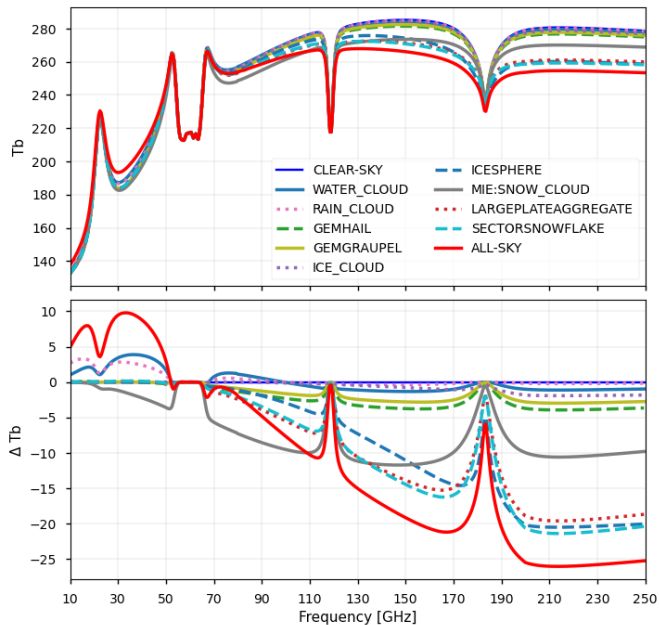


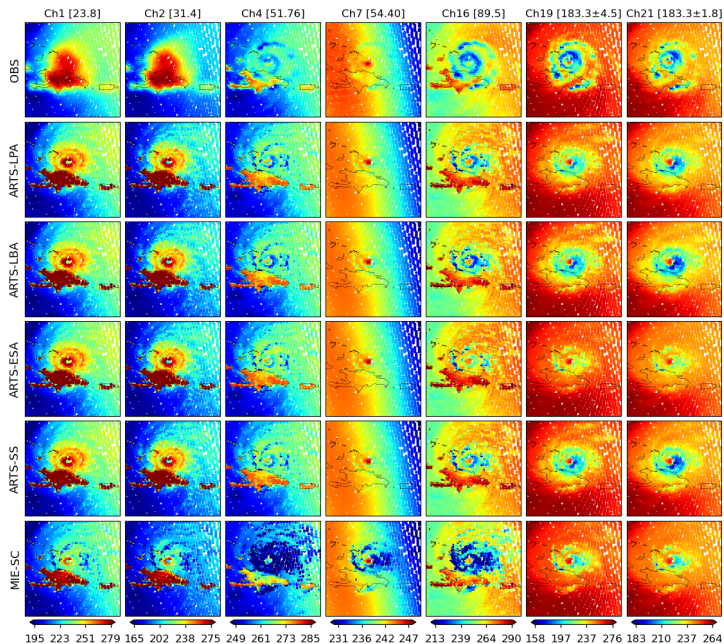
CRTM mass scattering parameters computed from the ARTS database for different habits at 94 GHz, 36 GHz, and 14 GHz and a temperature of 260 K

CRTM Interface Changes

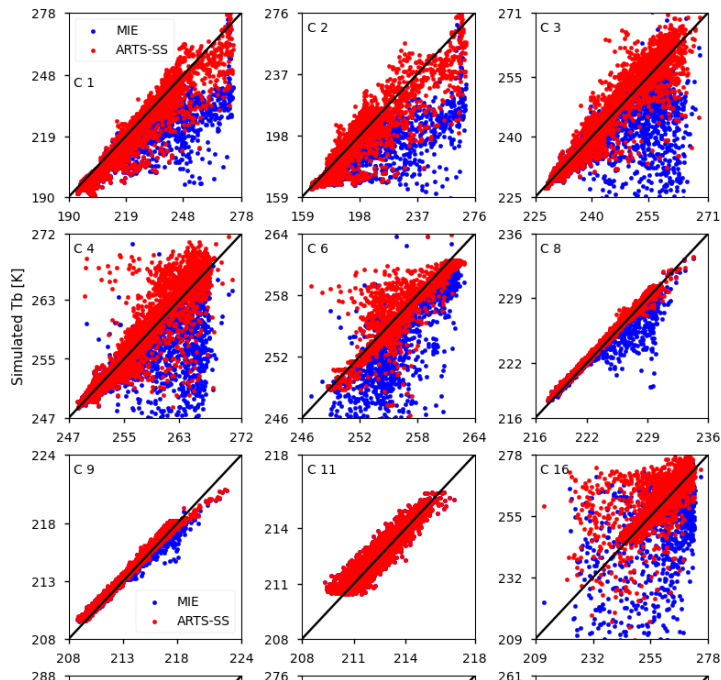
- ▶ Unless you want to use a new habit, no changes in the control files required!
- ▶ The code will check the CloudCoeff file and if Reff is not present then will use water vapor content for interpolation and ignore the effective radius even if provided.
- ▶ Effective radius is very subjective as cannot be measured so one would require to pick a method for calculating effective radius from water content, temperature, etc, but water content is often directly provided by the NWP model.
- ▶ In addition to the available cloud types (WATER_CLOUD, RAIN_CLOUD, SNOW_CLOUD, GRAUPEL_CLOUD, ICE_CLOUD, HAIL_CLOUD, which correspond to LiquidSphere, LiquidSphere, SectorSnowflake, GemGraupel, IceSphere, GemHail, the following cloud types can also be defined for the ARTS dataset (note that the word CLOUD is not required here):
PlateType1, ColumnType1, SixBulletRosette, Flat3_BulletRosette, Perpendicular4_BulletRosette, IconCloudIce, SectorSnowflake, EvansSnowAggregate, EightColumnAggregate, LargePlateAggregate, LargeColumnAggregate, LargeBlockAggregate, IconSnow, IconHail, GemGraupel, GemSnow, GemHail, IceSphere.

Sensitivity of MW frequencies to clouds



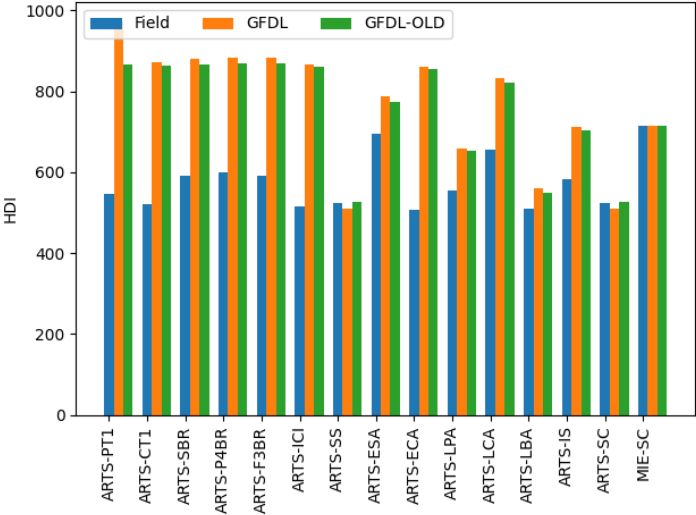


ATMS observed vs. CRTM simulated Tbs for Hurricane Irma, Sept 07, 2017 at 18 UTC, using IFS as input (all clouds considered) and different CRTM CloudCoef files.



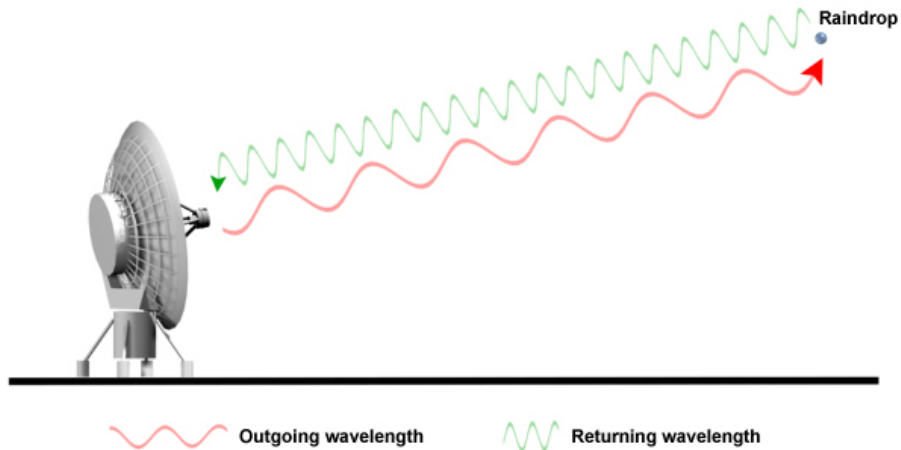
ATMS observed vs. CRTM simulated Tbs for Hurricane Irma, Sept 07, 2017 at 18 UTC, using IFS as input (all clouds considered) and different CRTM CloudCoef files.

PSD Impact on Results



The impact of PSD on calculated Histogram Difference Index

How active instruments work?



The radar equation

The radar equation can be formalized as follows:

$$R = \frac{10^{18} \lambda^4}{\pi^5 |k_w|^2} \beta_b \quad m^4 \quad m^2 m^{-4} m^1 \Rightarrow mm^6 m^{-3} \quad (1)$$

$$R_a = \frac{10^{18} \lambda^4}{\pi^5 |k_w|^2} \Gamma \beta_b \quad m^4 \quad m^2 m^{-4} m^1 \Rightarrow mm^6 m^{-3} \quad (2)$$

$$\beta_b = \int_0^\infty \sigma_b(D) n(D) dD \quad m^2 m^{-4} m^1 \Rightarrow m^{-1} \quad (3)$$

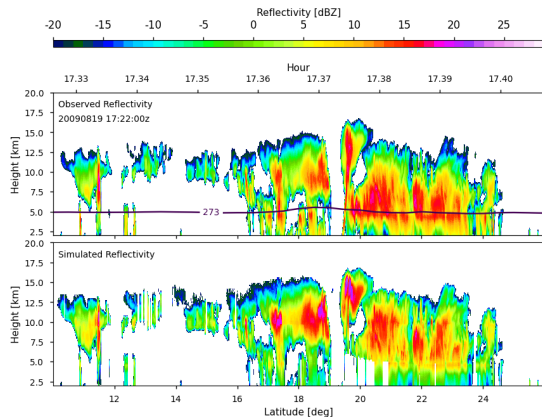
The unit for R (reflectivity) and R_a attenuated reflectivity are in $m^6 m^{-3}$ and 10^{18} is used to convert the unit to $mm^6 m^{-3}$. This is in turn converted to dBz or decibels by taking $R_e = 10 \log_{10} (R)$ or $R_{ea} = 10 \log_{10} (R_a)$. The dielectric factor (k_w) is calculated using the complex permittivity of the liquid water, $|k_w|^2 = 0.75$.

Transmittance (attenuation) depends on both scattering and absorption coefficients.

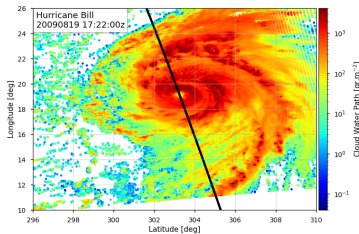
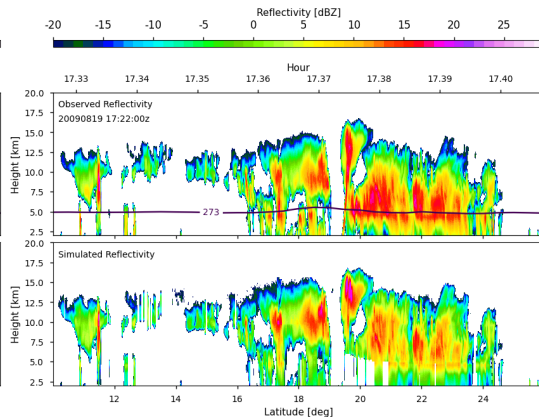
$$\Gamma(r) = \exp \left(-2 \int_{r_1}^{r_{sat}} k_e(r) dr \right) = \exp \left(-2 \sum_{i=r_1}^{r_{sat}} \tau(i) \right)$$

Attenuated Reflectivity (Sector Snowflake)

R_a dBz (IceSphere)

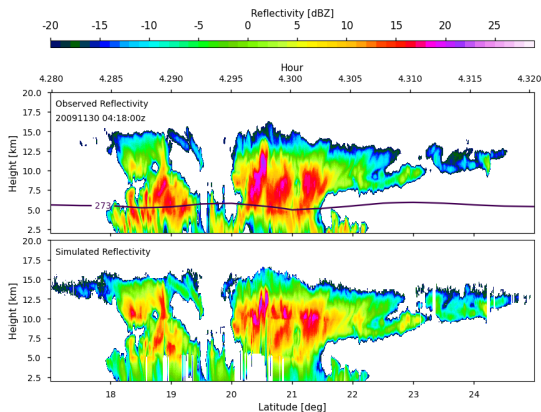


R_a dBz (ICE_CLOUD)

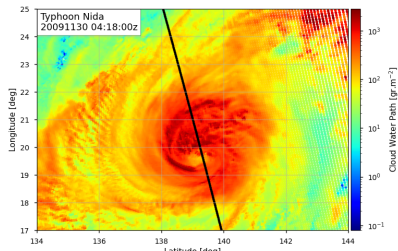
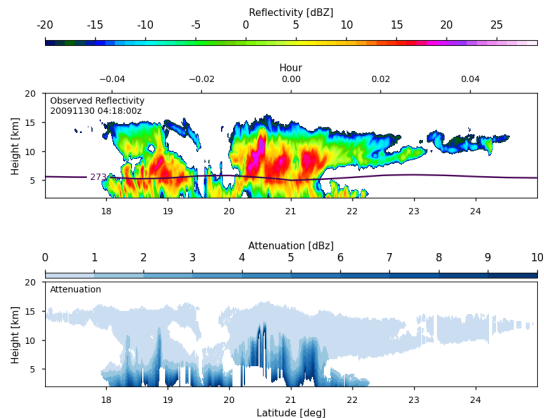


Attenuated Reflectivity (Sector Snowflake)

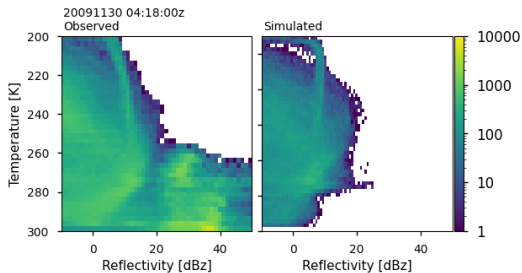
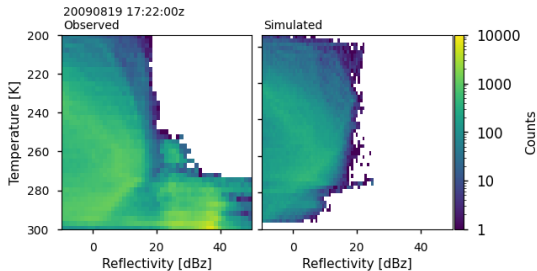
R_a dBZ (IceSphere)



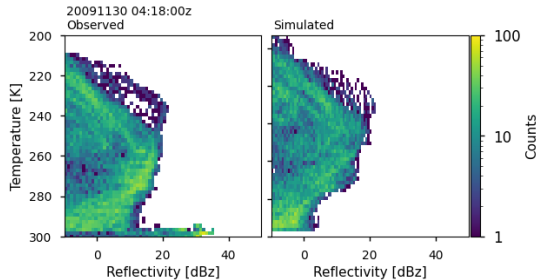
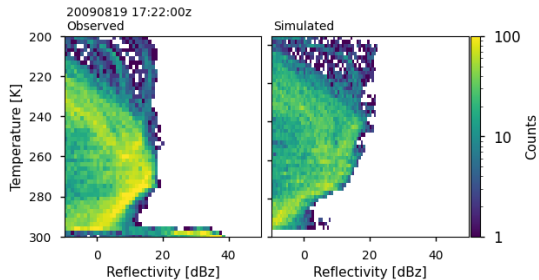
Attenuation dBZ (IceSphere)



Global



Tropical Cyclone



Conclusions

- ▶ A new scattering dataset generated using the DDA method was implemented into CRTM and evaluated using a collocated reanalysis and satellite dataset
- ▶ The new lookup tables no longer require parameters such as effective radius that are not provided by the model
- ▶ The new cloud coefficient is generated at much higher resolution for both frequency and mass/size
- ▶ The ARTS DDA lookup tables perform largely better than current CRTM cloud lookup tables
- ▶ CRTM radar simulator as well as its adjoint and tangent linear are implemented and tested
- ▶ The radar module takes advantage of different CRTM atmospheric absorption and cloud scattering modules
- ▶ The radar module can be used for the assimilation of observations from instruments such as CloudSat CPR, GPM DPR, and EarthCare CPR.
- ▶ Work is in progress to evaluate the active module especially within the JEDI DA system

Thank you for your attention!

Moradi et al. (2022). Implementation of a discrete dipole approximation scattering database into community radiative transfer model. JGR-Atmospheres, 127, DOI: 10.1029/2022JD036957

Moradi et al. (2023). Developing a Radar Signal Simulator for the Community Radiative Transfer Model. IEEE TGRS, Under Review.

B. Johnsson, 2023. The Community Radiative Transfer Model (CRTM): Community-Focused Collaborative Model Development Accelerating Research to Operations. BAMS, Under Revision.